The beta decay of ^{44}V

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We have calculated the β^+ decay of the proton rich nuclei ^{44}V in a full fp-shell valence space. We obtain a theoretical half-life of 71 ms compared with the experimental value $t_{1/2} = 90 \pm 25$ ms. Besides, we make predictions for the Gamow-Teller strength functions corresponding to the decays of the 2^+ ground state and 6^+ isomer state.

The study of Gamow-Teller processes in light nuclei has received considerable attention during the last years as a source of information both on the nuclear structure and on the behaviour of the axial vector weak current in the nuclear medium. The systematic analysis of (p,n) reactions, from which the Gamow-Teller (GT) strength can be extracted, has led to the conclusion that the experimental strength is depleted by a factor ~ 0.5 relative to the Ikeda sum rule [1]. This corresponds to a value of the ratio $\frac{g_A}{g_V}$ close to 1, instead of the free value 1.251. The same conclusion was reached in a careful analysis of the individual beta decay rates in the sd shell [2]. Nevertheless, the experiments carried out in the proton rich nuclei ^{33}Ar [3] and ^{37}Ca [4] have questioned these results. Owing to their very large Q_β values, these decays explore a large fraction of the GT strength function, including part of the GT giant resonance. The experimental results for the integrated strength are compatible with the theoretical predictions without any renormalization. Furthermore, in the ^{37}Ca case the GT strength functions obtained from the β^+ decay and from the (p,n) reaction are different [5]. These findings, even if subject to debate [6], shed doubts on the adequacy of the procedure of extraction of the GT strength from the (p,n) data. The conclusions of the sd shell analysis are also subject to criticism. For, in most of the decays studied, the only

available information refers to low-lying levels. Hence, what appears as a quenching of the GT strength could be also interpreted as a systematic shift of the calculated strength from the GT giant resonance towards the low-lying levels.

To clarify this situation it is important to study other β^+ decays in proton rich nuclei with large Q_β windows. ^{44}V is an excellent test case for several reasons. The energy released of its decay to ^{44}Ti is very large (Q_{EC}=13.7 MeV); a theoretical description of A = 44 nuclei, using a reliable effective interaction and a full $0\hbar\omega$ valence space, is feasible; and not the least important, results from a scheduled experiment at Ganil will come out soon [7]. This decay has two peculiar features that are worth commenting:

i) ^{44}V is the mirror of ^{44}Sc, an experimentally well know nuclei, therefore their wave functions are identical except Coulomb effects. When we compare the theoretical predictions for ^{44}Sc with the experimental data [8], we are checking simultaneously the quality of the ^{44}Sc and the ^{44}V wavefunctions.

ii) ^{44}Sc has an isomer state (6^+, $t_{1/2}$ = 2.44 d) at 0.271 MeV excitation energy. Hence, ^{44}V also will have a 6^+ state at an excitation energy close to 270 keV. Contrary to what happens in the decay of the ^{44}Sc isomer state, the ^{44}V isomer state is predicted to decay beta with a 100% branching ratio.

We use the fp shell as valence space, without truncations. The effective interaction is a slightly modified version of the Kuo-Brown [9] interaction, denoted KB3 in [10]. This interaction gives a fairly good description of the spectroscopy of nuclei in the lower and middle part of the fp-shell [10].

To test the quality of the wave functions, we have calculated the level scheme of ^{44}Sc, the mirror of ^{44}V. In figure 1 we can see that the theoretical predictions compare extremely well with the experimental results. Next we examine the E4 transition from the 6^+ isomer of ^{44}Sc to the ground state (2^+). Experimentally this decay mode proceeds with a 98.6% branching ratio, hence we disregard the contribution of the weak branch to the half-life.

Using effective charges 1.5 for protons and 0.5 for neutrons the prediction for the half-life is $t_{1/2}$ = 2.96 d in good agreement with the experimental result $t_{1/2}$ = 2.44 d. We have also computed the electron capture branching ratio (experimentally 1.4%) obtaining a 1% branching ratio to the only available state, a 6^+ T = 2 at 3.285 MeV in ^{44}Ca. The only state contributing significantly to the half-life of the ^{44}Sc ground state is the first excited state of ^{44}Ca. The predicted half-life is 1.13 h while the experimental result is 3.9 h.

We come to the $^{44}\mathrm{V} \longrightarrow {}^{44}\mathrm{Ti}$ decay. Our description of the ^{44}Ti spectroscopy is very satisfactory as it can be gathered from figure 2. The lowest 0^+ and 2^+ states are underbound due to the absence of core excited configurations in our approach. This shift would have to be taken into account when comparing the experimental and theoretical GT strength functions.

The half-life of ^{44}V is known experimentally to be $t_{1/2} = 90 \pm 25$ ms. The calculation gives $t_{1/2}$ = 49 ms using the bare value for (g_A/g_V). The agreement becomes excellent when we use $(g_A/g_V)_{\rm eff} = 0.77\ (g_A/g_V)_{\rm bare}$, in this case the result is $t_{1/2}$ = 71 ms. Once again it appears that there is too much GT strength in the low-lying states, the ones determining the half-life. This result is in the line of the findings of ref. [2]. The predicted GT strength function is plotted in figure 3. Notice that almost the whole of the predicted strength (80%) falls into the β^+ energy window.

Lets examine the behavior of the 6^+ isomer state of ^{44}V. The E4 transition to the ground state is predicted to proceed with a half-life $t_{1/2}$ = 1.08 days, using effective charges 1.5 for protons and 0.5 for neutrons. Due to the much larger value of the Q_β and to the availability of T = 0 and T = 1 states to decay to, the weak branch is dominant; $t_{1/2}$ = 66 ms using the bare value for (g_A/g_V). The predicted Gamow-Teller strength function for the 6^+ decay is plotted in figure 4. Most of the strength can be explored by the β^+ process. If the ground state and the 6^+ isomer state are simultaneously fed in an experiment we shall observe both decays in parallel with similar half-lifes.

In conclusion, we have computed the Gamow-Teller strength functions of the ground state and of the isomer 6^+ state of ^{44}V. These strength functions can be explored almost

completely by the β^+ decay. The comparison with the results of the experiment planned at Ganil will help us to understand better the renormalization of the axial vector weak current in nuclei.

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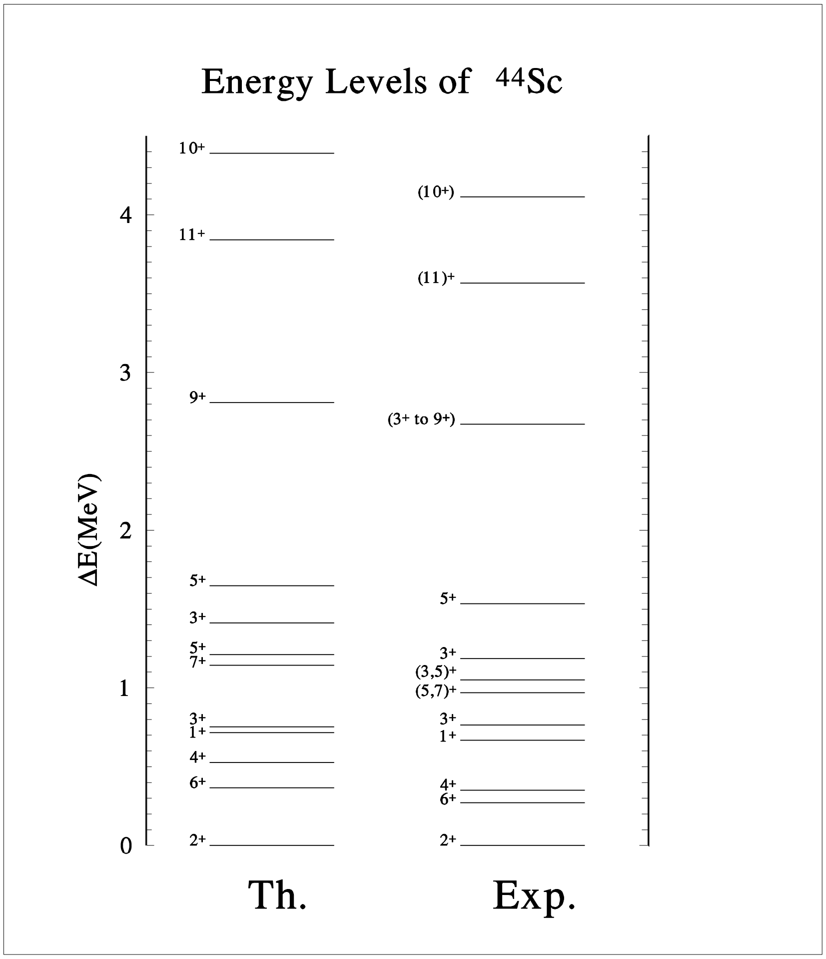

FIG. 1. Experimental and theoretical energy levels of ^{44}Sc.

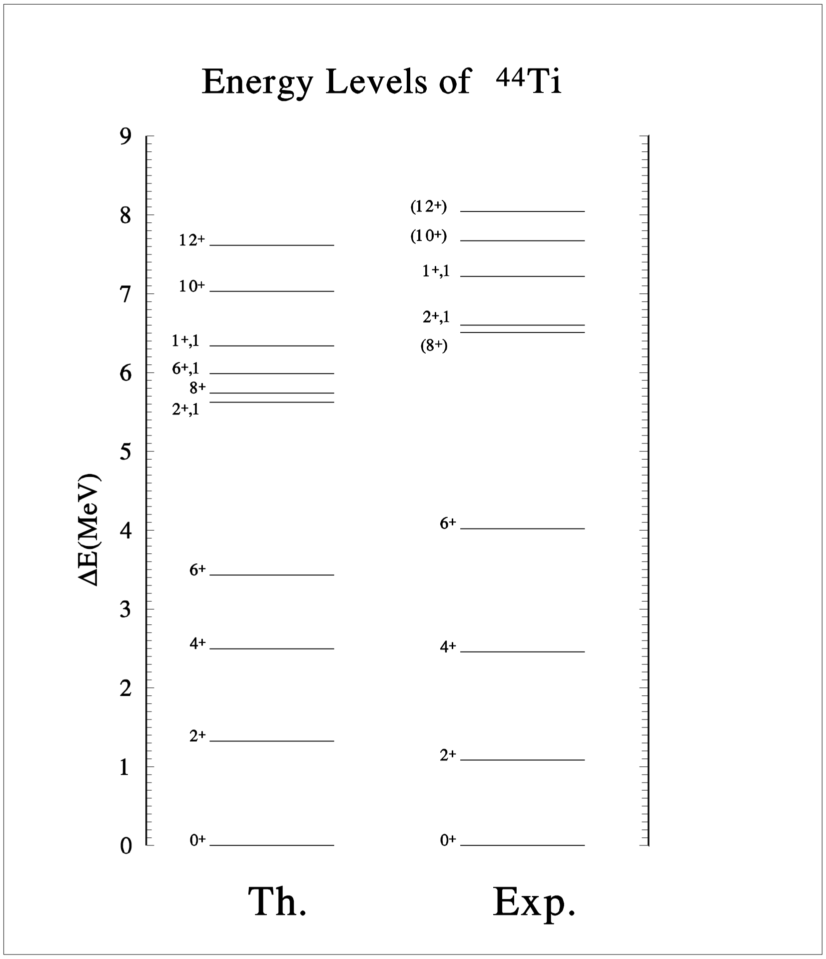

FIG. 2. Experimental and theoretical energy levels of ^{44}Ti.

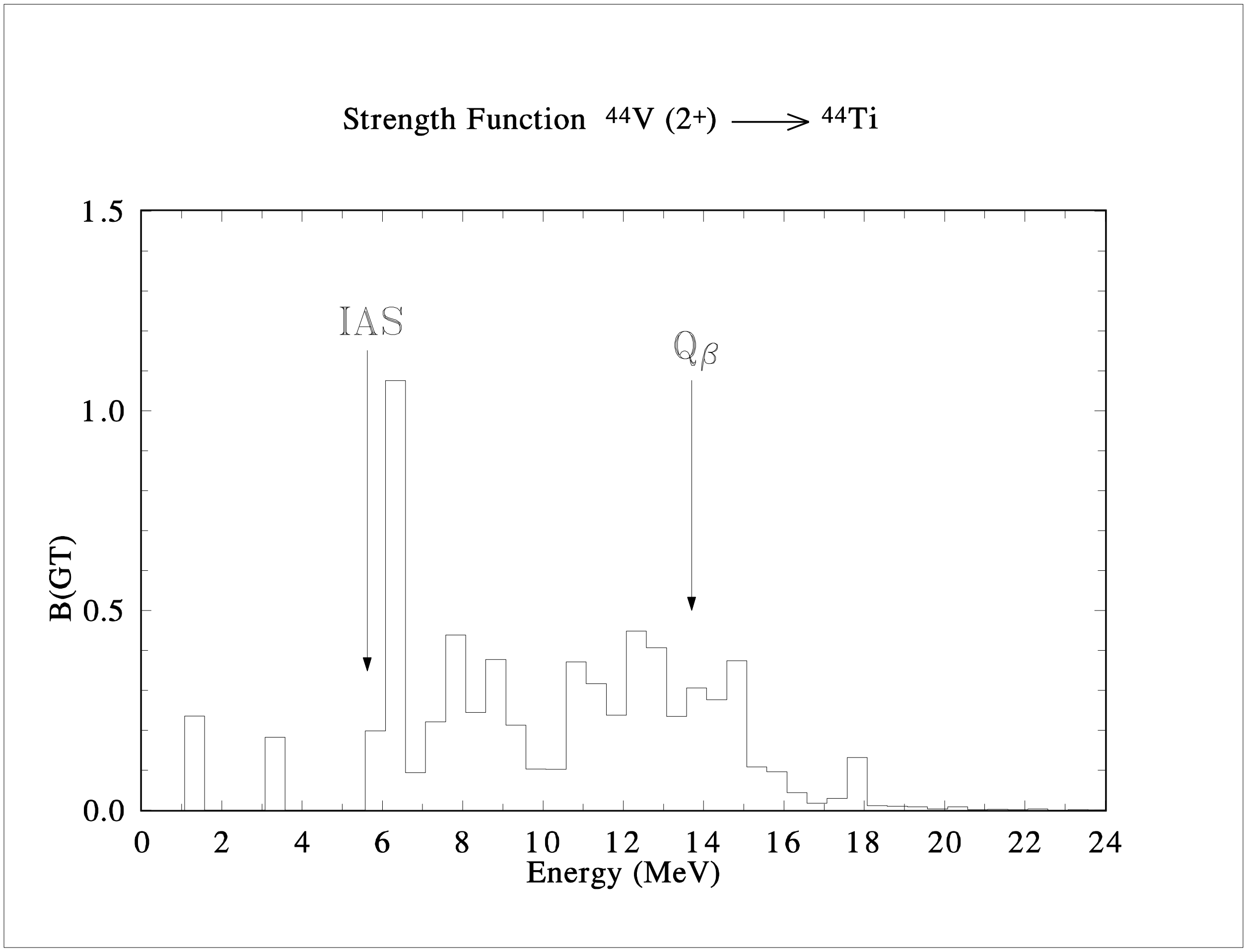

FIG. 3. ^{44}V $(2^+) \xrightarrow{\beta^+}$ ^{44}Ti Gamow-Teller strength function. $\mathrm{B(GT)} = \left(\frac{g_A}{g_V}\right)^2 \langle\sigma\tau\rangle^2$.

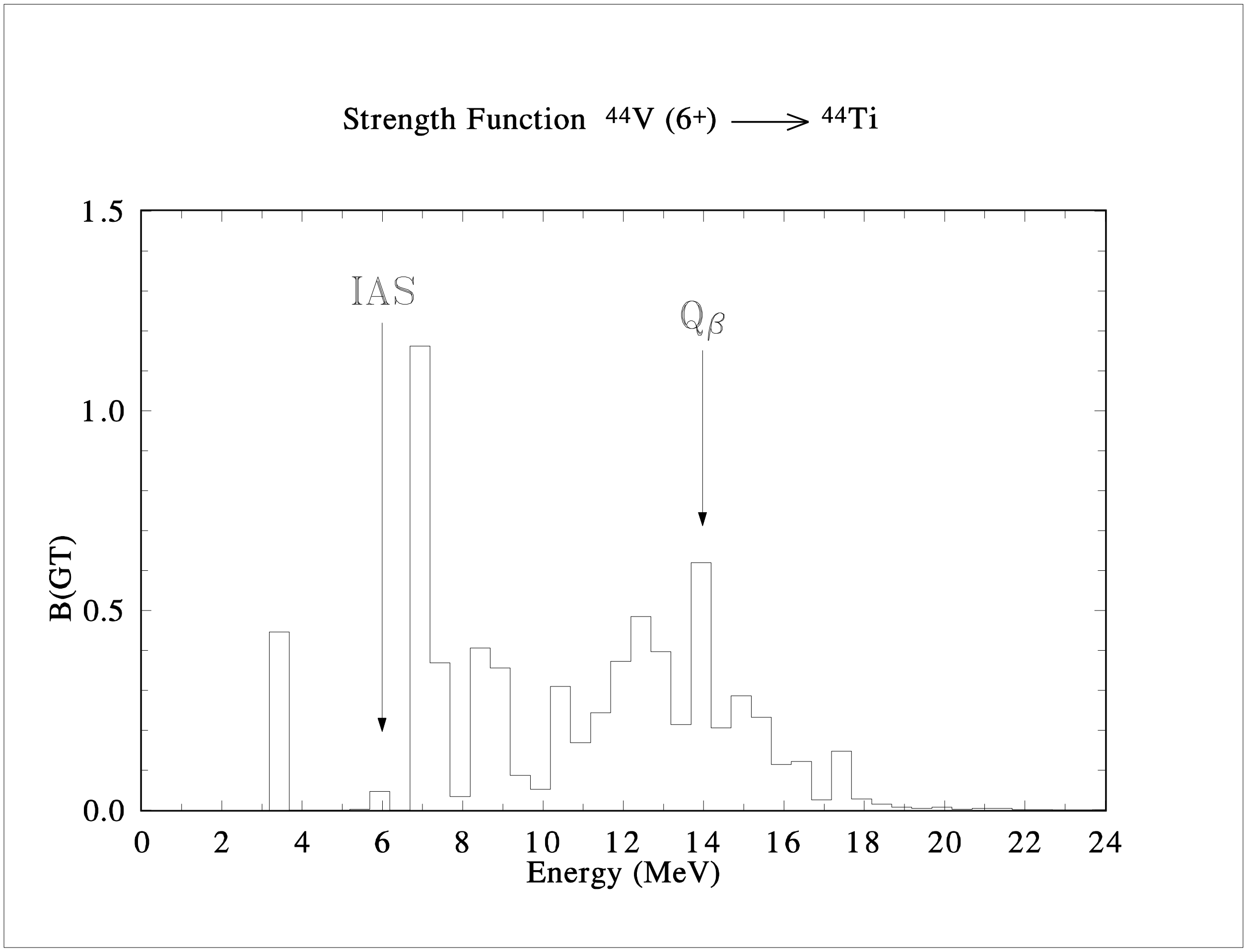

FIG. 4. ^{44}V $(6^+) \xrightarrow{\beta^+}$ ^{44}Ti Gamow-Teller strength function. B(GT) $= \left(\frac{g_A}{g_V}\right)^2 \langle\sigma\tau\rangle^2$.